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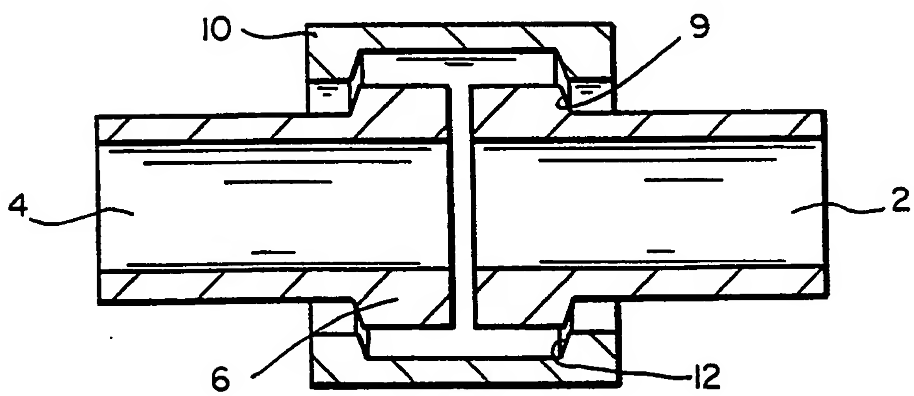

(57) Abstract

A radially heat-recoverable, especially heat-shrinkable, sleeve (10) is used to impart an axial force to two objects (2, 4). Axially facing surfaces (12) of the sleeve (10) coact with axially facing surfaces (9), one on each object. At least one, preferably both, of the surfaces of each of the pair of coacting surfaces is inclined to the axis of the objects. The sleeve (10) may be used to form a mechanical connection between the objects.

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METHOD OF APPLYING AXIAL FORCE BETWEEN TWO OBJECTS

Background to the invention

This invention relates to a method of applying an axial force between two objects, to an assembly of objects between which force has been applied, and to a radially heat-recoverable hollow sleeve for applying such a force.

An axial force may be applied between two objects in order to make a mechanical connection or to form a fluid-tight seal between them or between one or both of the objects and another object. For example, it is known to connect objects together mechanically by means of a screw clamp which engages a protruding rib which extends around each of the objects towards the end thereof. The clamp has a wrap-around configuration and is installed by rotation of one or more screw-fasteners which causes the diameter of the clamp to decrease. The surfaces of the clamp and the ribs are so configured that when the diameter of the clamp decreases, an axial force is imparted to the objects which causes one of the objects to be forced against the other object. However, the wrap-around configuration of the clamp, which is required in order to be able to reduce the diameter of the clamp, prevents the formation of seals directly between the clamp and the objects. The formation of seals requires the use of additional components of a deformable material such as elastomeric O-rings. Furthermore, the clamp is undesirably bulky in the overlap region.

An additional concern is that a considerable amount of space can be required in order to rotate the screw fasteners to cause the diameter of the clamp to decrease.

Summary of the invention

We have devised a technique for applying an axial force between two objects sing a radially heat-recoverable hollow sleeve, which is so configured that when the sleeve recovers radially, an axial force is applied between the objects.

A dimensionally heat-recoverable article is one whose dimensional configuration can be made to change significantly when subjected to heat. Usually such articles recover towards an original shape from which they have previously been deformed but they may simply adopt a new configuration without previously having been deformed.

In one aspect, therefore, the invention provides a method of applying an axial force between two objects positioned coaxially with respect to one another, each having an axially facing surface through which the force can be applied, the method comprising:

(a) positioning a radially heat-recoverable hollow sleeve so that the objects are in the direction of its recovery, the sleeve having two axially facing surfaces for coacting with respective axially

facing surfaces on the objects, at least one of the surfaces of each pair of coacting surfaces being inclined to the axis; and

(b) causing the sleeve to recover radially.

In another aspect, the invention provides a radially heat-recoverable hollow sleeve for applying an axial force between two objects positioned coaxially with respect to one another so as to force the objects towards one another, the sleeve having two axially spaced apart axially facing surfaces formed in its wall between and in contact with which the objects can be received, the surfaces being inclined to the axis of the sleeve so that an axial force is applied to the objects when the sleeve recovers radially.

Description of the invention

The use of a radially heat-recoverable sleeve in the technique of the present invention confers significant advantages. In particular, it makes it possible to create a seal directly between the sleeve and the objects without any need to use additional components such as elastomeric O-rings. This has the advantage that the quality of the seal between the objects is not controlled by the properties of such additional components, which can degrade over time as a result of the physical or chemical treatment to which the components are subjected.

Furthermore, elastic forces in the sleeve arising from unresolved recovery allow a seal between the objects through the sleeve to withstand a range of temperatures, even when the coefficients of thermal expansion of the objects and the sleeve differ. Such forces can be available over a wide range of dimensions by appropriate selection of sleeve and operating temperature. In addition, such forces can ensure that the seal can accomadate stresses imparted to the sleeve through the objects once it has been installed, for example as when the objects are subjected to bending, torsion and axial forces. Yet further, the unresolved recovery forces and the absence of threaded fasteners reduce the risk of weakening of the mechanical connection or the seal or both between the objects as a result of impulsive forces or vibration.

An additional advantage of the use of a heat-recoverable sleeve is that the space required to install it can be significantly less than that required to rotate the screw fasteners of previously used clamps. Moreover, the time and skill required to install a heat-recoverable sleeve can be significantly less than that required to install a clamp.

Yet another advantage of the use of a heat-recoverable sleeve is that it is able to accommodate a range of sizes of objects and furthermore can accommodate the tolerances to which the objects are manufactured for connection by means of the sleeve.

A further advantage of the use of a recoverable sleeve is that the connection between the objects can be made without permanent deformation of the objects. This allows the objects to be reused after the connection has been broken by removal of the sleeve, for example for repair of the objects or of components contained within the objects when hollow or of components attached to the objects.

The heat-recoverable sleeve may comprise more than one component, for example to facilitate manufacturing of the sleeve. For example it may comprise a heat-recoverable driver member and one or more inserts positioned in the direction of its recovery, the inserts having the axially facing surfaces for contacting the axially facing surfaces on the objects. More particularly, the driver may be in the form of a uniform band whose uniform surface acts against a uniform surface of the insert. The insert may, however, just provide an appropriate profile for the axially facing surface; it may be a ring-like insert having say a triangular cross-section.

The sleeve may be formed from a polymeric material which exhibits the property of elastic or plastic memory, as described for example in US-2027962, US-3086462 and US-3597372. The material may contain fillers which render it electrically conductive so that heat can be generated by passing an electric current through the material to cause the sleeve to recover. Particularly preferred conductive materials are based

on ultra high molecular weight polyethylene as disclosed in, for example, EP-A-157640.

Preferably the sleeve is formed from a shape memory alloy. Shape memory alloys exhibit a shape memory effect as a result of their ability to transform between martensitic and austenitic phases. The transformation may be caused by a change in temperature: for example, a shape memory alloy in the martensitic phase will begin to transform to the austenitic phase when its temperature increases to a temperature greater than A_s, and the transformation will be complete when the temperature is greater than A_f. The reverse transformation will begin when the temperature of the alloy decreased to a temperature less than M_s and will be complete when the temperature is less than M_f. The temperature M_s, M_f, A_s and A_f define the thermal transformation hysteresis loop of a shape memory alloy. An article may be formed in a desired configuration while in its austenitic phase. If it is then cooled so that it transforms to the martensitic phase, it can then be deformed so as to obtain a strain on recovery of up to about 8%. The strain imparted to the article is recovered when the article is subsequently heated so that it transforms back to the austenitic phase. Further information is available in the article by L. M. Schetky in Scientific American, Volume 241, pages 68 to 76 (1979) entitled Shape Memory Alloys.

Shape memory alloys have been used to form couplings for objects such as tubes. US-4198081 discloses a

radially shrinkable tubular coupling which has circumferentially extending teeth formed in its internal surface. Tubes to be coupled are positioned within the coupling. The coupling is then heated to cause it to shrink radially so that its teeth bite into the external surfaces of the tubes so as to grip the tubes. Such couplings apply a force to the tubes only in the radial direction and have the disadvantage that the coupling does not apply an axial force to the tubes so the tubes are not forced towards one another.

The shape memory alloy from which the sleeve is formed will be selected according to the temperatures to which the sleeve will be exposed before, during and after installation, and to the physical requirements placed on the sleeve when in use. The alloy may be based on copper, for example as disclosed in US-4144057 or US-4144104, or more preferably on nickel-titanium, for example as disclosed in US-3753700, US-4337090, US-4565589 or US-4770725. A preferred method of treatment of a nickel-titanium based shape memory alloy is disclosed in US-4740253. The subject matter disclosed in these documents is incorporated herein by these references to the documents.

Under certain conditions, and if processed in an appropriate manner, certain shape memory alloys exhibit pseudoelasticity. Pseudoelasticity allows an article to be deformed elastically by as much as 10%. It is discussed in a paper presented by T. W. Duerig and G. R. Zadno at the International meeting of the Materials

Research Society in Tokyo in June 1988. Particularly preferred are materials which exhibit "non-linear pseudoelasticity" which arises in appropriately treated alloys while they are in their austenitic phases at a temperature which is greater than M_d which is the maximum temperature at which the transformation of the alloy to its martensitic phase can be induced by the application of stress. An article formed by an alloy which exhibits non-linear pseudoelasticity can be deformed substantially reversibly by 8% or more. An advantage of a sleeve formed from an alloy which exhibits non-linear pseudoelasticity is that, over a range of strain, the stress is relatively constant. This peculiar property allows the sleeve to exert a relatively constant force on connected objects while accommodating tolerances to which the objects are manufactured, and stresses imparted to the sleeve through the objects.

The sleeve may be radially heat-expandable, so that the sleeve will recover outwardly to contact the objects positioned externally of the sleeve in the direction of its recovery.

Preferably the sleeve is radially heat-shrinkable, so that it recovers inwardly to contact the objects positioned within it.

The nature of the force that is applied to the objects can be selected by appropriate arrangement of the axially facing surfaces of the objects and the sleeve.

The axially facing surfaces of each of the objects, through which force is applied to that object, may be the surface which faces away from the other object. This can allow the sleeve to force the objects towards one another.

The axially facing surfaces of each of the objects, through which force is applied to that object, may be the surface which faces towards the other object. This can allow the sleeve to force the objects apart.

The surface of each pair of coacting surfaces which is inclined to the axis may be a surface of the sleeve or may be a surface of one of the objects, or may be a combination of the two. In some instances, it can be preferable for the coacting axially facing surfaces of both the sleeve and the objects to be inclined to the axis.

A seal between the coacting surfaces of each pair of surfaces may be optimized by appropriate profiling of one or both of the surfaces of each pair. For example a circumferential seal may be formed between each pair of coacting surfaces by arranging one of the surfaces to be planar (when viewed in longitudinal cross-section) and the other of the surfaces to be convex at the point at which the seal is made. The convex surface may, for example, be rounded or square at that point.

A seal may be provided between two coplanar surfaces, in which the angles between each of the surfaces and

the axis are approximately the same.

The angle between the axis and the axially facing surface of each pair of coacting surfaces which is inclined to the axis is selected according to the relative amounts of axial and radial displacement or force required to be imparted by the sleeve. Also relevant is the amount of friction between the coacting surfaces. Preferably the angle is greater than about 20°, more preferably greater than about 45°. Preferably the angle is less than about 85°, more preferably less than about 75°.

The friction between the coacting surfaces may be reduced by providing lubricating material between them. This may be achieved by providing a coating of a lubricant on one of the coacting surfaces of each pair, preferably the surfaces of the sleeve. Polytetrafluoroethylene is a preferred lubricant.

A coating on one or both of the coacting surfaces can also enhance the seal between them as a result of its deformation. Such a coating may be of a metallic or a polymeric material.

The technique of the present invention may be used to form a mechanical connection between two objects by forcing the objects towards one another. When the sleeve is heat-expandable, the objects will generally be hollow, at least at their ends, in order that the sleeve may be positioned within the objects. When the

sleeve is heat-shrinkable, the objects are preferably, but need not be, hollow. For example, the objects may be pipes or tubes which are circular in cross-section. The axially facing surface on each of the objects may be provided by a radially extending flange, which may be located towards an end of the object. Such a flange may stand proud of the surface of the object, or it may be defined by a groove.

The mechanical connection between the objects may involve another object. For example, the two objects to be connected may have another object positioned between them, or under them to support them against the radially force which is exerted as the sleeve recovers.

The technique may be used to force two objects apart; for example, one of the objects may provide a surface against which to exert a force to force the other object against a third object. For example, a first object may be tubular and the second object may be a shaft which extends through the tubular first object and which bears a radially extending flange. The sleeve may act between the hollow first object and the flange to draw the shaft through the hollow first object. This arrangement could be used, for example, to suspend equipment through an aperture in a bulkhead, in which a collar surrounds the aperture to serve as the first object, and the equipment is suspended from the shaft on the opposite side of the bulkhead from the collar. As the shaft is drawn through the aperture by recovery of the sleeve, a seal can be formed between the bulkhead and the equipment.

Brief description of the drawings

Figure 1 is a schematic longitudinal cross-section through two pipes to be connected by means of a radially heat-shrinkable sleeve;

Figure 2 is a schematic longitudinal cross-section through the pipes and the sleeve shown in Figure 1, the pipes being connected by means of the sleeve;

Figure 3 is a schematic longitudinal cross-section through two pipes which are connected by means of a radially heat-shrinkable sleeve and through another object;

Figure 4 is a schematic longitudinal cross-section through a shaft which extends through an aperture in a bulkhead; and

Figure 5 is a schematic longitudinal cross-section through the shaft and bulkhead shown in Figure 4, being mechanically connected to one another by means of a radially heat-shrinkable sleeve.

Description of preferred embodiments

Figures 1 and 2 show two cylinders 2.4 positioned in abutting relationship, each having a radially outwardly extending flange 6 towards its end. The surface 9 of the flange on each of the cylinders which faces away from the other of the cylinders is inclined to the axis of the

cylinders. The angle between each of the surfaces and the axis is about 70°.

A tubular sleeve 10 is formed from a nickel-titanium based shape memory alloy, such as a nickel-titanium-iron alloy as disclosed in US-3753700 or a nickel-titanium-niobium alloy as disclosed in US-4770725. The alloy is processed so that the sleeve can be made to shrink radially by the application of heat.

The sleeve 10 has two axially spaced apart axially facing surfaces 12 formed in its internal wall between which the flanges 6 can be received. The surfaces 12 are inclined to the axis of the sleeve. The angle between the axis and the surfaces is about 70°.

The axially facing surfaces 12 of the sleeve 10 have a coating of a lubricating material such as polytetrafluoroethylene.

Application of heat to the sleeve (which can be effected simply by removal of the sleeve from a cryogenic fluid in the case of some alloys) causes it to shrink radially. Coaction of the axially facing surfaces of the sleeve and the objects on recovery of the sleeve results in a component of the force exerted by the sleeve acting radially inwardly, and another component action axially so that the ends of the cylinders are forced axially towards one another.

By appropriate preparation of the axially facing surfaces of the cylinders and the sleeve, seals can be formed

between them so that the connection between the cylinders through the sleeve is substantially fluid-tight.

Figure 3 shows a connection between two cylinders 13, 15 each having a radially outwardly extending flange 17 towards its end. The cylinders are positioned with a support 19 positioned within the end portions of the pipes. The support has a radially outwardly extending flange 21 which extends between the ends of the pipes, so that the ends of the cylinders abut it.

A radially heat-shrinkable tubular sleeve 23 has two axially spaced apart axially facing surfaces 25 formed in its internal wall between which the flanges 17 on the cylinders 13, 15 can be received. The surfaces 25 are inclined to the axis of the sleeve.

Application of heat to the sleeve causes it to shrink radially. The axially facing surfaces 25 of the sleeve coact with axially facing surfaces 27 of the flanges 17 on the cylinders. At the point on the surfaces 27 of the flanges with which the surfaces 25 of the sleeve coact, the surfaces of the flanges are convex; in fact the surfaces are square.

The recovery force exerted by the sleeve 23 on the cylinders 13, 15 includes a radial component and an axial component. The support 19 controls radial deformation of cylinders caused by the radial component of the recovery force. The axial component of the recovery force forces the cylinders axially towards one another, into contact with the flange 21 on the support 19.

Figures 4 and 5 show a connection between a shaft 41 and a bulkhead 43 having an aperture therein and a collar 45 around the aperture. The shaft 41 bears a radially extending flange 47, at one end and an item of equipment 49, which it is desired to suspend from the bulkhead 43, at its other end. The flange or the equipment may be fastened to the shaft after the shaft has been inserted through the aperture, for example by means of a lock pin inserted through the shaft, or a threaded fastener, or a bayonet fitting arrangement. However fastened it will generally be important that the flange and the equipment are fixed axially relative to the shaft.

The collar 45 and the flange 47 have axially facing surfaces 51,52 which are inclined to the axis of the shaft, the angle between each of the surfaces and the axis being about 70°. The inclined faces 51 on the collar 45 face those 52 on the flange 47.

A radially heat-shrinkable sleeve 53 formed from a nickel-titanium based shape memory alloy is positioned around the shaft between the collar 45 and the flange 47. The sleeve 53 has axially facing surfaces 55 which are inclined to the axis of the sleeve. The angle between each of the surfaces 55 and the axis is about 70°.

Application of heat to the sleeve 53 causes it to shrink radially. Coaction of the axially facing surfaces of the sleeve, and the collar and the flange on recovery of the sleeve results in a component of the

force exerted by the sleeve acting radially inwardly, and another component of the sleeve acting axially so that the collar and the flange are forced axially apart, and the shaft is drawn through the aperture. By appropriate arrangement of the surfaces of the shaft and the aperture, a seal can be formed between them. The sleeve 53 can therefore be used to suspend the equipment 49 from the bulkhead 43, and to form a seal between the two.

What is claimed is:

1. A method of applying an axial force between two objects positioned coaxially with respect to one another, each having an axially facing surface through which the force can be applied, the method comprising:

   (a) positioning a radially heat-recoverable hollow sleeve so that the objects are in the direction of its recovery, the sleeve having two axially facing surfaces for coacting with respective axially facing surfaces on the objects, at least one of the surfaces of each pair of coacting surfaces being inclined to the axis; and

   (b) causing the sleeve to recover radially.

2. A method as claimed in claim 1, in which the axially facing surface of each of the objects, through which force is applied to that object, is the surface which faces away from the other object.

3. A method as claimed in claim 1, in which the axially facing surface of each of the objects, through which force is applied to that object, is the surface which faces towards the other object.

4. A method as claimed in claim 1, in which the axially facing surfaces of the objects, which coact

with the axially facing surfaces of the sleeve, are inclined to the axis.

5. A method as claimed in claim 1, in which the axially facing surfaces of the sleeve, which coact with the axially facing surfaces of the objects, are inclined to the axis.

6. A method as claimed in claim 1, in which the coacting axially facing surfaces of the sleeve and of the objects are inclined to the axis.

7. A method as claimed in claim 1, in which the or each axially facing surface of each pair of coacting surfaces which is inclined to the axis is planar when viewed in longitudinal cross-section.

8. A method as claimed in claim 1, in which the angle between the axis and the axially facing surface of each pair of coacting surfaces which is inclined to the axis is from about 20° to about 85° at the point of contact between the surfaces.

9. A method as claimed in claim 8, in which the said angle is from about 45° to about 75°.

10. A method as claimed in claim 1, in which the axially facing surface is provided on each of the objects by a radially extending flange towards the end of each of the objects.

11. A method as claimed in claim 1, in which the objects are hollow.

12. A method as claimed in claim 1, in which one of the objects is tubular and the other of the objects is a shaft which extends through the tubular object, the shaft bearing a radially outwardly extending flange which provides the axially extending surface.

13. A method as claimed in claim 1, in which the sleeve is radially heat-shrinkable.

14. A method as claimed in claim 1, in which the sleeve comprises a shape memory alloy.

15. A method as claimed in claim 1, in which a circumferential seal is formed between each pair of coacting surfaces, one of the surfaces being planar and the other of the surfaces being convex at the point at which the seal is made.

16. A radially heat-recoverable hollow sleeve for applying an axial force between two objects positioned coaxially with respect to one another so as to force the objects towards one another, the sleeve having two axially spaced apart axially facing surfaces formed in its wall between and in contact with which the objects can be received, the surfaces being inclined to the axis of the sleeve so that an axial force is applied to the objects when the sleeve recovers radially.

17. A sleeve as claimed in claim 16, in which the sleeve is radially heat-shrinkable and the said axially facing surfaces are formed in its internal wall.

18. A sleeve as claimed in claim 16, in which each of the axially facing surfaces is planar when viewed in longitudinal cross-section.

19. A sleeve as claimed in claim 18, in which the angle between the axis and each of the axially facing surfaces is from about 20° to about 85°.

20. A sleeve as claimed in claim 19, in which the said angle is from about 45° to about 75°.

21. A sleeve as claimed in claim 16, which comprises a shape memory alloy.

22. A sleeve as claimed in claim 21, in which the alloy is a nickel-titanium based alloy.

23. A sleeve as claimed in claim 16, in which the said axially facing surfaces thereof are coated with a layer of deformable material.

24. A sleeve as claimed in claim 23, in which the deformable material comprises polytetrafluorethylene.

25. An assembly of interconnected objects, between which a force has been applied by a method as claimed in claim 1.

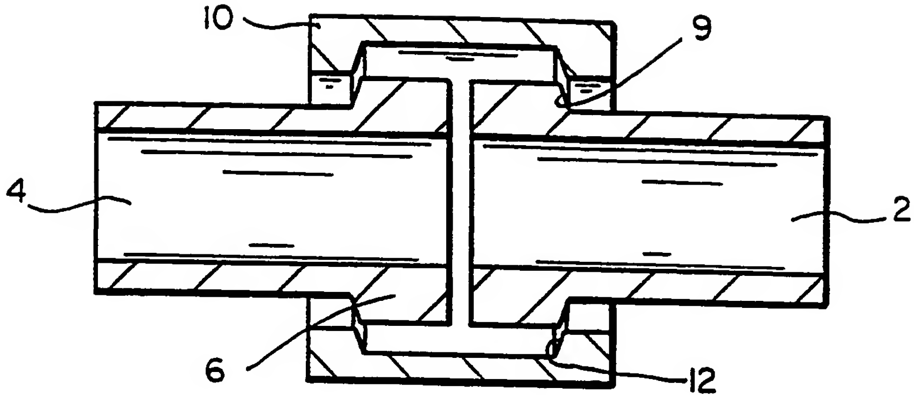

FIG_1

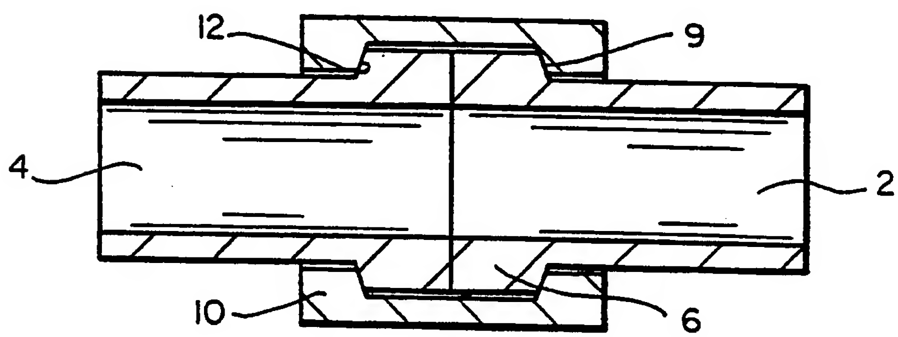

FIG_2

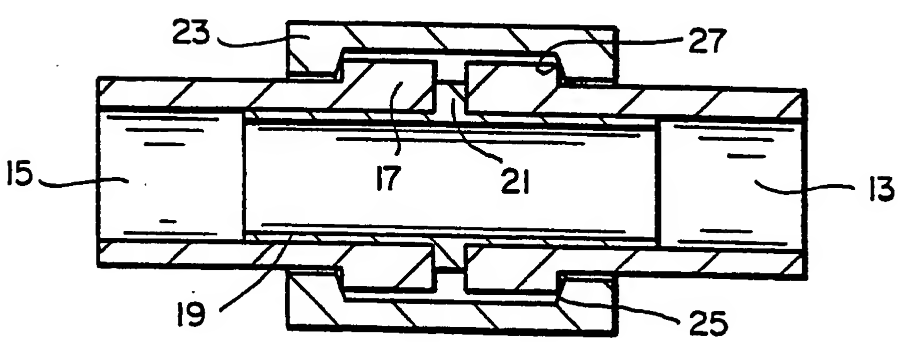

FIG_3

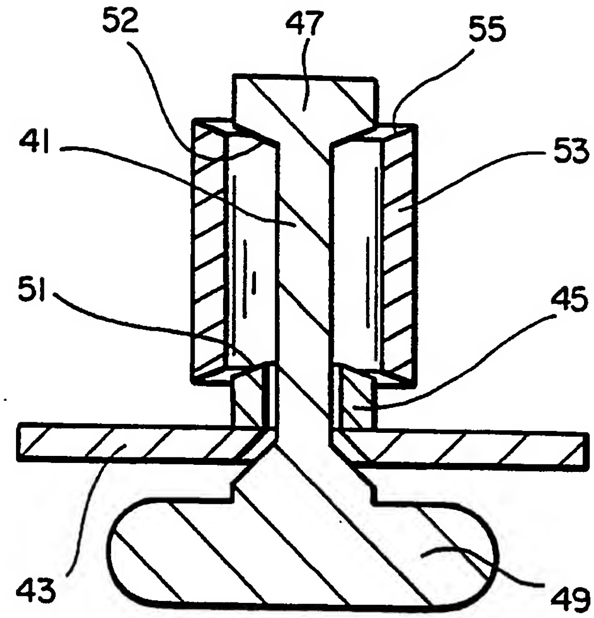

FIG_4

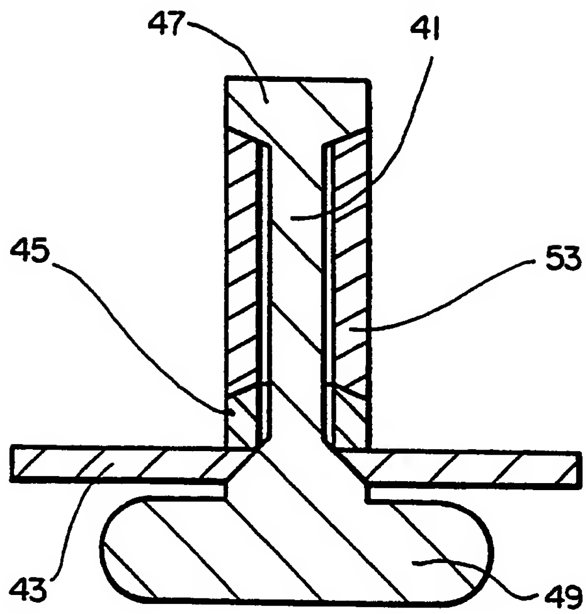

FIG_5

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 90/01935

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 F16L13/00 ; B23P11/02

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	F16L ; B23P

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
X	FR,A,2547631 (COMMISSARIAT A l'ENERGIE ATOMIQUE ET NOVATOME) 21 December 1984 see page 8, line 20 - page 9, line 14; figures 3a, 3b ---	1, 2, 4, 5, 6, 7, 10, 11, 13, 16 17, 18
A	CH,A,555023 (G FISCHER AG) 15 October 1974 see column 3, lines 3 - 27; figures 1, 5, 6, 7, 8 ---	1, 2, 3, 4, 5, 6, 7, 11, 13, 14 15, 16, 17, 18, 21

° Special categories of cited documents : [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
19 JULY 1990	14.08.90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	HUBEAU M.G.

1

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

US 9001935
SA 36149

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 19/07/90
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR-A-2547631	21-12-84	None	
CH-A-555023	15-10-74	None	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82